Phoenix: A 3U CubeSat to Study Urban Heat Islands

Arizona State University

NOAA Remote Sensing License Application

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Section I: Corporate Information

1.1 Names and Addresses

This application is made by:

Arizona State University
School of Earth and Space Exploration

781 E Terrace Mall
ISTB4 - BLDG 75
Tempe, AZ 85287-6004

Phone: 480-965-5081
Fax: 480-965-8102
Web: http://sese.asu.edu

The individuals listed below constitute the leadership team for the Phoenix CubeSat and are employees or students of Arizona State University (ASU).

Name	Relation	Street Address	Mailing Address	Telephone	Citizenship
Prof.. Judd Bowman	Principal Investigator	781 E Terrace Mall Tempe, AZ 85287	PO Box 876004 Tempe, AZ 85287		US Citizen
Dr. Daniel Jacobs	Faculty Advisor	781 E Terrace Mall Tempe, AZ 85287	PO Box 876004 Tempe, AZ 85287		US Citizen
Sarah Rogers	Student Team Leader	781 E Terrace Mall Tempe, AZ 85287	PO Box 876004 Tempe, AZ 85287		US Citizen

1.2. Description of Agreements with Foreign Entities

None to report.

1.3. Charter of Agreement

Phoenix is a Student Flight Research Opportunity funded through the NASA Undergraduate Student Instrumentation Program. The team is supported by NASA Cooperative Agreement No. NNX16AI68A. The grant agreement is included as an attachment to the submission of this application.

Section II Launch Segment Information

2.1. Proposed Launch Schedule

Phoenix has been accepted into NASA's CubeSat Launch Initiative with an aim to be manifested for a launch in winter of 2018/2019.

2.2. Proposed Launch Vehicle Source

At this time, there is no information on launch provider.

2.3. Proposed Launch Site

At this time, there is no information on launch site.

2.4. Anticipated Operational Date

Launch readiness of the spacecraft is scheduled for September 8, 2018. Launch is anticipated in January 2018 with the CubeSat enter operation immediately following launch.

2.5. Orbits and Altitudes

An ISS orbit has been requested with nominal configuration:

Apogee: 401 km
Perigee: 409 km
Inclination Angle: 51.6°
Orbital Period: 90 minutes

Section III: Space Segment

3.1. System Overview

System Name: Phoenix CubeSat
Number of Satellites in System: 1

Phoenix is an educational mission that consists of a 3U CubeSat designed by an undergraduate student team at Arizona State University to monitor the Urban Heat Island Effect through thermal infrared remote sensing. All mission data will be open to the public and amateur participation will be encouraged. The satellite's payload sensor is the Tau2 640 Infrared Camera, which is a commercial, uncooled microbolometer produced by FLIR Technologies. The payload provides a resolution of 640 x 512 pixels with a pixel size of 17μm. The camera will be fitted with a 100mm lens yielding a 6.2° x 5° field of view and a typical ground footprint of 43 by 35 km. Nadir spatial resolution is 68 m/pixel, with 100 m/pixel typical. UHF and S-band radios operating in amaetur bands will provide uplink/downlink communication. A GPS receiver will be used for clock synchronization and localization. Two Earth horizon sensors, sun sensors, and magnetometers will be used for attitude determination, along with three reaction wheels for attitude control. The spacecraft will have no propulsion. Mission operations are expected last up to two years and yield a total of 8,000 thermal IR images. The primary targets will be U.S. cities.

3.2. Sensor Performance

The Tau2 is the only imaging sensor that the satellite will contain. It yields the following performance specifications.

3.2.1. Anticipated Best Theoretical Resolution: 68 m/pixel

$\text{Alt} = 400 \times 10^3$ *meters*
$\text{IFOV} = 0.17 \times 10^{-3}$ *radians per pixel*

$\text{Resolution} = IFOV \times Altitude$
$= 68 m/pixel$

3.2.2. Field of View: 43 x 35 km (Nadir pointing, altitude of 400km, orientation random)

Formula: $2 \times Altitude \times \tan(FOV/2)$
$\text{Alt} = 400 \times 10^3$ *meters*
$\text{FOV} = 6.2° \times 5°$

$\text{Y\_Swath} = 2 \times Alt \times \tan(6.2/2)$

$= 43\ km$

X_Swath $= 2 \times Alt \times tan(5/2)$

$= 35\ km$

3.3. On Board Storage Capacity

The payload will pass all captured images to the onboard computer to be initially stored and later downlinked through S-Band amateur frequencies. The flight computer will have 16GB of solid state storage, allowing for storage of 8,000 uncompressed images.

3.4. Navigation Capabilities

Orientation of the satellite will be controlled by the MAI-400 ADCS, a COTS component designed and manufactured by Maryland Aerospace which provides a pointing error of <0.5° deg (1-sigma). Additional tracking supported by GPS receiver with an accuracy of 1.5m RMS. The satellite has no propulsion systems.

3.5. Imaging Properties

3.5.1. Time delayed integration with focal plane

10 ms (specified by FLIR)

3.5.2. Oversampling Capability (Q)

1.08 ***(****calculations can be found in appendix B)*

3.5.3. Image Motion Parameters

The spacecraft will acquire all images with target tracking to reduce motion blur to 15 meters (<25% IFOV).

3.6. Anticipated System Lifetime

2 years (based on atmospheric drag calculations from the NASA DAS)

Section IV: Ground Segment

4.2. Communications Links

4.2.1. Command (uplink/downlink)

Frequencies: 435-438 MHz (amateur UHF band)
UHF Transmission Footprint: ~1000km (90d FWHM beam at 430km)

4.2.2. Mission Data (downlink): 2400-2450 MHz (amateur S-band)

S-Band Transmission Footprint: 190 km *(calculations can be found in appendix B)*

Downlink Data Rate:

- **UHF Downlink (health beacons) :** 9600 bps
- **S-Band Downlink (images):** 2Mbps

Plans for communications Crosslinks: None

4.3. Protection of Communications Links

Phoenix is a student project, to stay within the limited budget and capabilities of the team, it will operate in the UHF and S amateur bands. To meet the requirements of both the educational nature of the project, all data will be public from capture onward, without any cost or restriction, and some functionality (ping and stored image retrieval) will be operable by amateurs. These commands will be published shortly after launch and commissioning.

Operation Integrity
To maintain the integrity of the mission operations, the activities of the satellite will only be controlled by the mission operations team, who are specifically trained on how to control the satellite while it is in orbit. Study areas will be focused on select U.S. cities and secondary targets of geological interest. Control codes for pointing, image capture, mode switch, and other mission critical operations will be ciphered with a rotating key one-time pad using a simple substitution scheme. The cipher dictionary will be kept in a private repository on github protected by gpg public/private key pairs.

System Data Collection and Processing

UHF amateur bands will be used for uplinking commands and for downlinking all housekeeping telemetry. Limited live housekeeping telemetry will be broadcast as a regular beacon. A beacon parser application will be published to allow amateurs to verify aliveness and assess basic health. A full dump of telemetry history can be commanded by the ASU ground station. Uplinks of command schedules will occur as necessary.

Image files will be downloaded on the S-Band link during passes over the ASU ground station, when not imaging the Phoenix area. The predicted backlog can be downlinked in one pass, which will typically last 5-10 minutes. After minimum science goals are met, the image downlink command will be published to the amateur community as an update to the beacon parser app allowing amateurs to receive images and send them to the Phoenix team.

Ground Station

Command and downlink will be performed at the ASU Tempe campus, using the university's Satellite Ground Station and mission control center. Embry Riddle Aeronautical University (ERAU) located in Prescott, AZ will be used as a backup station for performing mission critical command. There is no backup ground station which will be able to support gathering images over S-Band frequencies. Amateur operators will help relay beacon health telemetry and images.

Data Processing

All downlinked image data will be formatted in standard image processing formats, such as BMP, TIFF, etc. Mission Operators will upload the image into Arcmap GIS to associate points to a geospatial location and process the image further as a GeoTIFF (.geotiff) format.

Data Distribution

Part of Phoenix's mission is to serve as an educational resource, which includes a mandate to make all data as well as some satellite operations open to the public. Satellite telemetry will be received by amateurs using commonly available software in combination with a telemetry parser app distributed by the team. All data will be published on the program's websites (including phxcubesat.asu.edu), where the public can use and view the thermal images (both raw and post-processed forms), mission operations code, satellite telemetry, and scientific results as information is published on a weekly basis. After an initial period of operations, images will be available for downlink by suitably equipped amateurs who will submit images to the project archive.

In addition, all satellite health data, raw images, and data analysis will be stored in a Data Archive Library at ASU, a digital repository for all documents created throughout the program. Both raw data as well as design reviews, program requirements, published papers and scientific observations would be stored here for ease of access to the public. The student team will do a bulk update the content deposited in the library once a month with health logs and raw image data and once each quarter with any updates to the science analysis performed.

Section V: Other Information

A. Distribution of Unenhanced Data

Raw data will be made publicly available on the program's website and the digital repository curated by ASU libraries.

B. Commercial Distribution of Data

All files made available to the public will be available for free under a Creative Commons BY 4.0 or similar license which permits all reuse with proper attribution.

C. Post Mission Disposition

The satellite will undergo natural orbital decay until burning up on reentry. Per calculations performed using the NASA Debris Assessment Software, DAS, the impact causality area upon the satellite's reentry into the earth's atmosphere is 0.00 m^2, and the risk of human causality is 1:100,000,000.

Appendix A: Acronyms

Acronym	Interpretation
ADCS	Attitude Determination and Control System
ASU	Arizona State University
BMP	Bitmap
COTS	Commercial off the Shelf
CSLI	CubeSat Launch Initiative
ERAU	Embry Riddle Aeronautical University
GeoTIFF	Geographic Tagged Image File Format
GIS	Geographic Information Software
GPS	Global Positioning System
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
OBC	On Board Computer
ODAR	Orbital Debris Assessment Report
TIFF	Tagged Image File Format
UHF	Ultra High Frequency
USIP	Undergraduate Student Instrument Project

Appendix B: Calculations:

FLIR Imaging Parameters

Oversampling Capability

p $= 17 \times 10^{-6}$ *(pixel pitch, in meters)*
$FN = 1.6$
$\lambda = (10.5 + 12.5)/2$ *(mean detected camera wavelength)*
$\lambda = 11.5 \times 10^{-6}\ \mu m$

$Q = (\lambda \times FN)/p$
$Q = 1.08$

Antenna Footprint

S-Band Antenna Footprint

H = *1312000 (altitude, in feet)*
BW *= 60 (beamwidth of the S-Band antenna, in degrees)*
A = *80 (greatest target tracking angle, in degrees)*

outer_radius = $[H/(\tan(A-(BW/2)] \times 8497.104$ *(km)*
inner_radius =$[H/(\tan(A+(BW/2))] \times 8497.104$ *(km)*

S-Band Footprint = *outer_radius + inner_radius*
= 190 km

UHF Antenna Footprint

~1000km (90deg FWHM beam at 430km)